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	Engineering and Design CALIBRATION OF LABORATORY SOILS TESTING EQUIPMENT	
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ENGINEERING AND DESIGN

CALIBRATION OF LABORATORY SOILS TESTING EQUIPMENT

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

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Office of the Chief of Engineers
Washington, D. C. 20314

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Calibration of Laboratory Soils Testing Equipment

1. Purpose. This manual presents recommended procedures for the calibration of testing equipment commonly used in Corps of Engineers soils laboratories. As a supplement to EM 1110-2-1906, "Laboratory Soils Testing," it has been prepared as an aid in establishing and maintaining acceptable accuracy for soils testing equipment.

2. Applicability. The provisions of this manual are applicable to all Corps of Engineers divisions and districts having Civil Works functions.

3. References.

a. EM 1110-2-1906,

b. Relevant Federal Specifications, ASTM publications, and special reports are listed in Appendix A. These references are identified in the main text by number as listed in the appendix.

4. Introduction.

a. Need for Calibration of Equipment. Soil test results are only as accurate as. the procedures and equipment used to produce them. By constant vigilance and regular, careful calibration and inspection of equipment, laboratory personnel can ensure acceptable accuracy of test results. The necessary frequency of calibration depends on the type and use of equipment. A record should be kept containing the actual calibration data: date of calibration, names of persons doing the calibration, and information on calibration devices and methods used.

b. The Laboratory Environment.

(1) In addition to the requirement for maintaining equipment of known accuracy, a soils laboratory should maintain control of the testing environment. Areas in which consolidation, permeability, triaxial (especially with pore water pressure measurements), direct shear, and, to a lesser extent, hydrometer analyses and compaction tests are performed should be maintained at a reasonably comfortable uniform temperature with a range in temperature not to exceed ±5 F; otherwise the test results often become erratic and questionable. The resolving of ambiguous test data is often possible by means of a

continuous chart record of room temperature.

(2) A central forced draft system, where the air is heated or cooled as required, filtered to remove dust, and returned through ducts to the various parts of the laboratory, is generally the most satisfactory means of temperature control. In areas where undisturbed soil samples are stored or test specimens are prepared, a high relative humidity should be maintained. To measure the humidity of such areas, a wet and dry bulb thermometer or a direct indicating dial hygrometer may be used. Dial hygrometers frequently need checking to ensure a reasonable accuracy; this may be easily done by using a sling psychrometer or a wet and dry bulb thermometer. Erroneous and erratic results may be obtained on some soils under conditions of low relative humidity when liquid and plastic limits tests are being made. Operations that produce dust such as sieving, processing, or pulverizing should be conducted in an area separate from the main laboratory, and an adequate means of removing, the dust from the atmosphere, either by filtration or exhausting to the outside, should be provided. Noisy operations such as sieving, compaction, and maximum density tests should be conducted in rooms separate from the main laboratory because of their adverse effect on other laboratory personnel. If possible, the laboratory floor should be concrete. Many testing devices are driven by motors which should be isolated from the soil specimens being tested. Special rubber or cork pads can be used to mount shear and consolidation equipment, isolating them from objectionable vibration. Generally, to be detrimental a vibration must be of such amplitude as to be more than barely perceptible. One simple method to determine the magnitude of vibration is to place a beaker of water on the platform holding the test specimen and observe the water surface. An unrippled water surface usually indicates, for routine testing, a level of vibration not detrimental to the specimen being tested. Tests of long duration, such as consolidation, shear, etc., on sensitive soils, require a much more vibration-free testing environment than insensitive soils or short testing times.

(3) Areas in the laboratory that receive direct sunlight or heat from other sources such as radiators, ovens, and hot plates should be avoided for those tests where temperature changes adversely affect test results, for example, consolidation, triaxial shear (especially where pore water pressure is measured), and hydrometer analyses where a constant-temperature water bath is not used.

(4) There are some types of balances, particularly the newer single-pan, top-loading balances, that are sensitive to air currents. These should either be properly shielded or located in areas where air currents from the heating or cooling system do not interfere with their proper operation.

5. Linear Measurements. The specific device to be used for making linear measurements depends upon the accuracy required; however, several of the devices listed in Table 1 have about the same degree of accuracy and could be used interchangeably. Linear measurements are made for two basic purposes: (a) to establish the accuracy of testing equipment and (b) to measure the physical phenomena occurring in a test to determine the properties of the soil sample.

Table 1. Linear Measuring Equipment

Device	Range	Smallest Reading	Application
Flexible metal printed tape	0-10 ft	1/32 in.	Fall of compaction rammer
Engraved metal or hardwood rules	0-30 cm 0-100 cm	1/2 mm 1 mm	Head in permeability tests Size of permeameters
Cathetometers	0-40 cm 0-100 cm	0.1 mm	Size of cylindrical cutters, compaction molds
Calipers			
Vernier	0-13 cm 0-6 in.	0.1 mm 0.001 in.	Size of cylindrical cutters
Micrometer	0-6 in.	0.001 in. 0.0001 in.	Size of molds, shear boxes
Dial gages	0-0.5 in. 0-1 in. 0-12 in.	0.0001 in. 0.001 in. 0.001 in.	Consolidation, change in thickness, and deformation of shear specimens under applied loads
Optical reticles	0-0.5 in.	0.005 in.	Liquid limit grooving tools, standpipe diameters, sieve openings
Linear potentiometers Differential transformers	0-0.5 in. 0-2 in. 0-4 in.	0.001 in. 0.01 in. 0.01 in.	Axial or horizontal deformation of specimens in shear tests
Gage blocks	0-1 in. 0-25 mm		Primary standards for checking measuring equipment

a. Rules and Tapes. Rigid steel rules that have machine-divided graduations are suitable for measurements to 0.01 in. These rules may be used as primary standards to check flexible printed-scale steel tapes should this ever become desirable.

b. Cathetometers. Cathetometers (Fig. 1.) are suitable for linear measurements that require a precision between that provided by machine-divided metal rules and vernier or micrometer calipers. Cathetometers are usually 40 or 100 cm in length and read to 0.1 mm by means of a vernier. Instruments with higher precision but shorter lengths and reading to 0.01 mm are available. Because readings are made by means of a telescope with cross hairs, cathetometers are particularly suited for making measurements where it is impractical or difficult to contact the object being measured, e.g. heights of liquid in manometers or standpipes. Other instruments similar to cathetometers are available; most of these have short ranges (15-cm maximum). Some of these instruments are toolmaker's microscope, measuring microscope, and a low-power (10X) microscope with a cross-hair reticle in the eyepiece and a graduated mechanical stage. Cathetometers and similar instruments may be calibrated with a vernier caliper (reading to 0.001 in.) or a micrometer caliper by setting a known length between the jaws of the caliper; this distance is then measured with the instrument being calibrated. Care should be taken to ensure that the plane of the jaws of the caliper is perpendicular to the line of sight of the telescope on the cathetometer.

c. Optical Reticles. Optical reticles or micrometer disks are glass disks, 20 to 27 mm in diameter, on which are accurate scales, typically 0-10 mm or 0-0.5 in. long (Fig. 2). A suitable instrument is available from Edmund Scientific Company, 600 Edscorp Building, Barrington, New Jersey 08007, as their Catalog No. 30055, 12X magnifier, and Catalog No. 30585 reticle. Similar instruments are available from most of the scientific supply companies. Reticles either are used with magnifiers (called measuring magnifiers or pocket comparators) or are inserted into the optical system of a low-power (10X) microscope. Because the object and scale are both magnified, good accuracy is easily secured. Reticles are very convenient for small linear measurements such as the diameter of permeability standpipes, dimensions of liquid limit grooving tools, and sieve openings. To calibrate an optical reticle, it should be assembled in the magnification system in which it will be used: A suitable distance is then set between the jaws of either a vernier or micrometer caliper (reading to 0.001 in.) and the distance as read using the reticle determined. If available, a stage micrometer may also be used to check a reticle. Stage micrometers are glass slides, 25 by 75 mm, with scales ruled directly upon them Either reflected or transmitted light may be used with the stage micrometer.

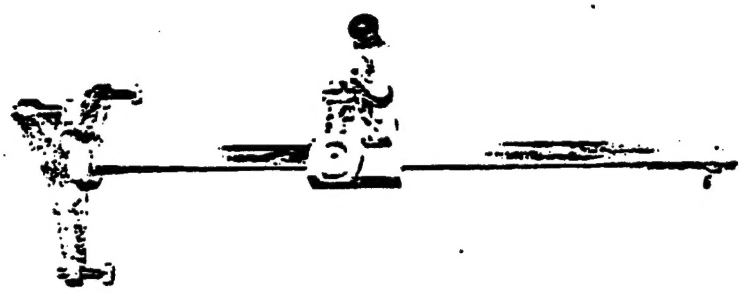


Fig. 1. Cathetometer

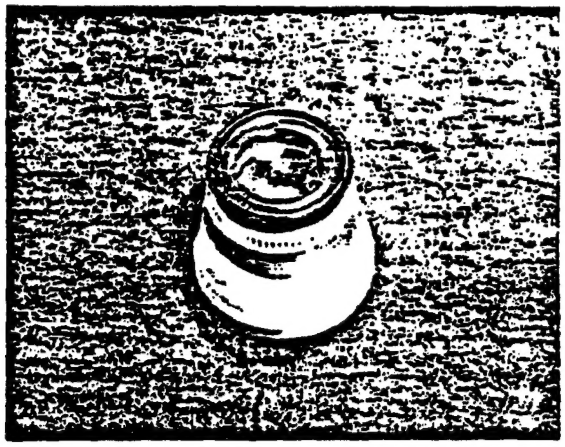


Fig. 2. Optical reticle in a pocket magnifier

d. Calipers. Calipers (Fig. 3) are made in a variety of styles and degrees of precision. Vernier calipers with dual scales reading to 1/128 in. and to 0.1 mm are available. Vernier calipers are also made reading to 0.001 in. or, if metric measurements are preferred, to 0.02 mm. Micrometer calipers usually read to 0.001 in. or to 0.0001 in. Micrometer calipers are also made reading to 0.01 mm. Micrometer calipers are not as versatile as vernier calipers because a separate tool is required for outside and inside measurements. Usually, for the same range and precision, micrometer calipers are more expensive than vernier calipers. A machinist's 0- to 6-in. vernier caliper reading to 0.001 in. is useful for the measurement of soils testing equipment such as compaction molds, direct shear boxes and cutters, consolidation rings, and height of drop gage for liquid limit tests. Calipers may be checked for accuracy by using gage blocks of the appropriate size (para g below). Usually checks at three or four settings of the calipers are sufficient to establish their accuracy. Tools of good design are provided with an adjustment of the zero setting when the jaws are closed. This adjustment varies with the tool, and the manufacturer's instructions should be followed in setting the zero reading. Care should be taken not to close the jaws of the calipers too tightly either when making a measurement or the zero adjustment of a reading on a gage block. Some micrometer calipers are provided with a ratchet stop to eliminate this possibility.

e. Dial Gages.

(1) Dial gages (Fig. 4) are used extensively for linear measurements in soil testing, the most common use being the measurement of specimen dimensions before and during testing. When equipped with special holders or stands, dial gages are useful in calibration of equipment for measuring inside diameters and heights of cylinders, inside dimensions of direct shear boxes, and specimen cutters. In load rings, they are used to measure deflection (loads). Dial gages are available in ranges from 1/4 to 12 in. and graduations of 0.0001, 0.0005, 0.001, and 0.01 in. in the English system and in ranges from 0.625 to 200 mm and graduations of 0.001, 0.0025, 0.005, 0.02, and 0.01 mm in the metric system. The most commonly used dial gages in soil testing are those in the 0- to 0.3- and the 0- to 0.5-in. ranges with 0.0001 graduations and the 0- to 1.000-in. range with 0.001 graduations. For most soils laboratory testing, jeweled bearings and shockproof movements are unnecessary.

(2) To calibrate dial gages, a suitable holder or stand should be obtained (Fig. 5). A precise plane surface .on which the dial gage contact point will rest must also be provided. The dial gage should be carefully mounted so that the axis of the dial stem is perpendicular to the

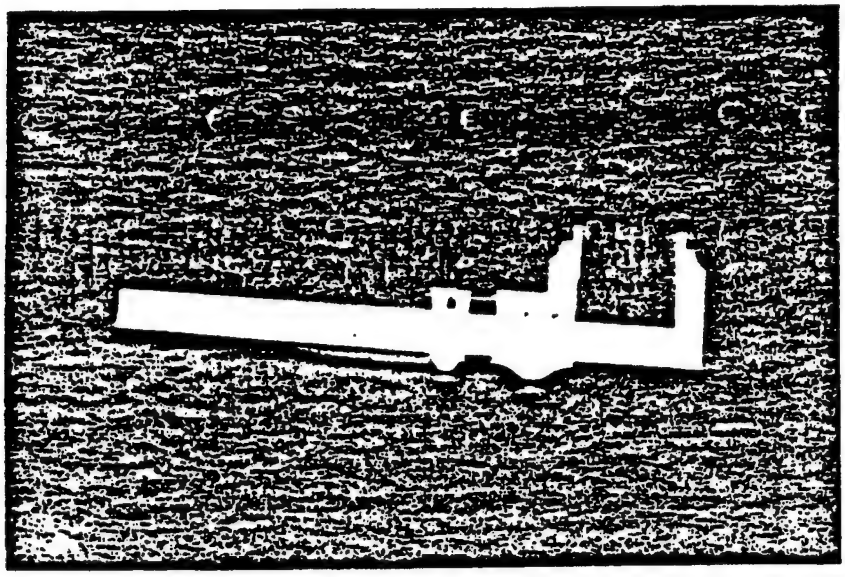


Fig. 3 Vernier calipers

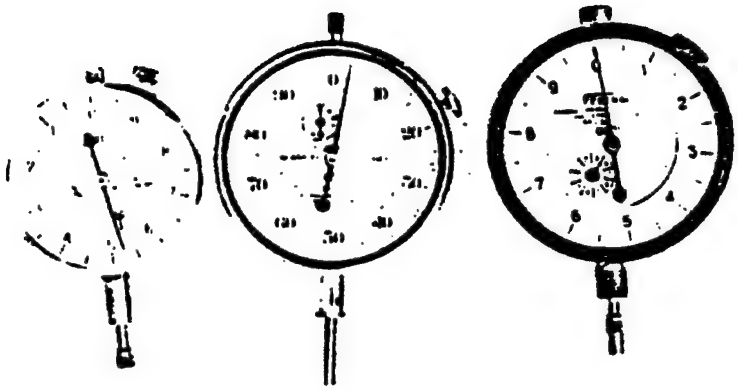
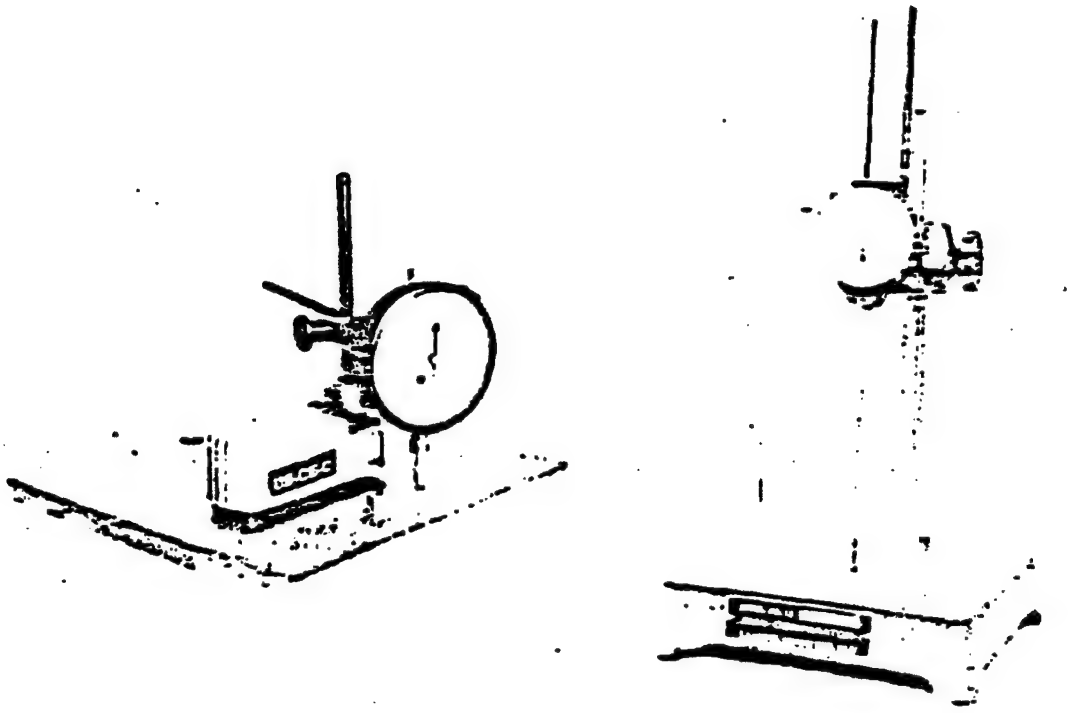


Fig. 4. Typical dial gages



a. Dial gage with magnetic holder b. Dial gage with stand

Fig. 5. Dial gage, with magnetic holder and stand

plane surface. Gages with clockwise dials should be set at zero reading and the desired size gage block then inserted under the contact point and the dial reading taken. Gages with counterclockwise dials should be set at zero with the desired size gage block under the contact point. The gage block is then removed, and the contact point allowed to come in contact with the plane surface and the dial then read. This operation should be repeated at several points along the dial gage's travel. Care should be taken not to allow the dial gage hands to spin too rapidly as the measurements are made, as damage to the instrument or erroneous reading's may occur.

f. Electrical Devices. Electrical devices (Fig. 6) such as rectilinear potentiometers and differential transformers are used with appropriate indicating or recording equipment to measure deformation of soil specimens during testing., They are particularly useful where it is

desirable to record test data in the absence of the operator (for example, in tests of long duration, such as direct shear tests that extend into off-duty hours). Electrical devices are calibrated using gage blocks or feeler (thickness) gages, using a procedure similar to that used for dial gages.

Fig. 6 Rectiliner potentiometer, 1/2-in. range

g. Gage Blocks. Gage blocks (Fig. 7) are metal blocks with two parallel faces machined to a very accurate dimension. They are used as primary standards for the calibration or checking of practically all the linear measuring devices previously discussed, micrometer calipers, dial gages, and electrical devices. Gage blocks should be kept clean and dry, and should be stored in boxes provided for them when not in use. They should be handled preferably with gloves or with clean, dry hands and wiped with a clean, dry cloth before storing after use. When stacked in

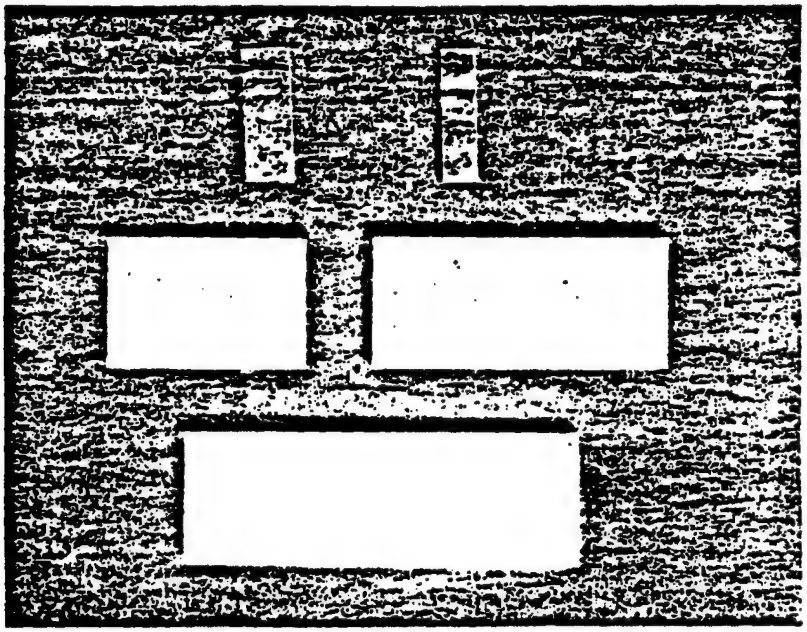


Fig. 7. Gage blocks

use, care should be taken that no dust particles are between the contact faces.

6. Volumetric Measurements.

a. Cylinders and Molds. The volume of trimming cylinders and compaction or maximum-minimum molds should be determined either by linear measurements or by the water-filling method as described below:

(1) Volume by Linear Measurement. Using either a vernier or micrometer caliper and a metal rule, determine the inside diameter and height of the container. Determine the average of four equally spaced height measurements and the average of four equally spaced measurements of the inside diameter. Have a second technician verify all measurements and compute the volume of the container.

(2) Volume by Water-Filling Method. The bottom of a cylinder open at both ends should be placed on or clamped to a section of plate glass or metal and sealed against water leakage at the contact edges using wax, stopcock grease, or similar sealant. Fill the cylinder slightly above its rim with distilled, deaired water and place a section of plate glass over the surface to eliminate the meniscus. Take care to entrap no air bubbles. Determine the weight of water required to fill the container, taking into account the temperature of the liquid in determining its density. At least three determinations of volume should be made.

b. Volumetric Flasks.

(1) Volumetric flasks used in the determination of specific gravity of soils should be calibrated as outlined in EM 1110-2-1906, Appendix IV. Preliminary to the calibration, the flask should be cleaned using a synthetic detergent, followed by several rinses with distilled water. It is important that the neck of the flask where the calibration mark is located be thoroughly clean and uniformly wetted so that a good meniscus is developed by the water.

(2) In view of the calibration expense, flasks of borosilicate glass (Pyrex, Kimax) should be used as they are much more resistant to breakage. Flasks that comply with the requirements for Type 1, Class B, flasks of Federal Specification NNN-F-289 (reference 13) are suitable for specific gravity testing.

c. Graduated Cylinders. Graduated cylinders when used as sedimentation jars in hydrometer analysis are of sufficient accuracy to be used without calibration. Graduated cylinders used for the measurement

of volume in routine soils testing, such as the constant-head permeability test, should comply with requirements for Type 1, Style 1, cylinders of Federal Specification NNN-C-940 (reference 12), which specifies volume accuracies as follows:

Nominal capacity, ml	10	25	50	100	200	250	500	1000	2000
Maximum allowable tolerance, ml	±0.1	0.3	0.4	0.6	1.4	1.4	2.6	5.0	10.0

For greater accuracy, use Class A or "Certified" cylinders that meet the requirements for accuracy of National Bureau of Standards Circular 602 (reference 7), which specifies maximum tolerance in volume of approximately one-half that given above. Graduated cylinders selected as meeting the appropriate criteria should not require calibration by the user. If it is desired, however, calibration can be made by the following procedure:

Weigh the cylinder filled to the capacity mark with distilled water.

Subtract the weight of the clean, dry cylinder.

Determine the temperature of the water.

Determine the volume at 20 C (standard temperature for volumetric glassware calibration) from the following tabulation.

Test Temp □C	Apparent Wt of 1 liter of Water, g	Test Temp □C	Apparent Wt of 1 liter of Water, g
15	997.93	21	996.99
16	997.80	22	996.81
17	997.66	23	996.61
18	997.51	24	996.39
19	997.36	25	996.16
20	997.18		

The tabulation above takes into account the buoyancy of air when weighing with brass weights, and the coefficient of cubical expansion of glass. Because of their large diameter relative to height, graduated cylinders are not suitable for measurements when accuracy better than 1 percent is required.

d. Burettes, Pipettes, and Standpipes. Burettes are available in capacities from 10 to 1000 ml, but only rarely are sizes larger than 50 ml used. Pipettes are available in capacities of 0.1 to 25 ml. If a burette or pipette is selected having a capacity slightly in excess of the

volume to be measured, it will not be necessary to calibrate it before use in routine and most research soils testing. Should calibration be desired, it is done by weighing the water metered from the apparatus. The piece should be cleaned before calibration so that the inside is uniformly wetted. A rinse with alcohol and then distilled water is usually sufficient. The piece should be mounted vertically and filled with distilled water at 20 C so that the bottom of the meniscus coincides with the zero mark. The water in appropriate amounts is then allowed to flow into a glass weighing bottle or an Erlenmeyer flask (of known weight) and weighed. The term standpipe as used herein refers to small-bore (maximum 10 mm) transparent tubes of glass or rigid plastic, having no graduation markings to indicate volume. To calibrate a standpipe, an arrangement such as that shown in Fig. 8 is used. The standpipe is held vertically, and its bottom end is connected, using a

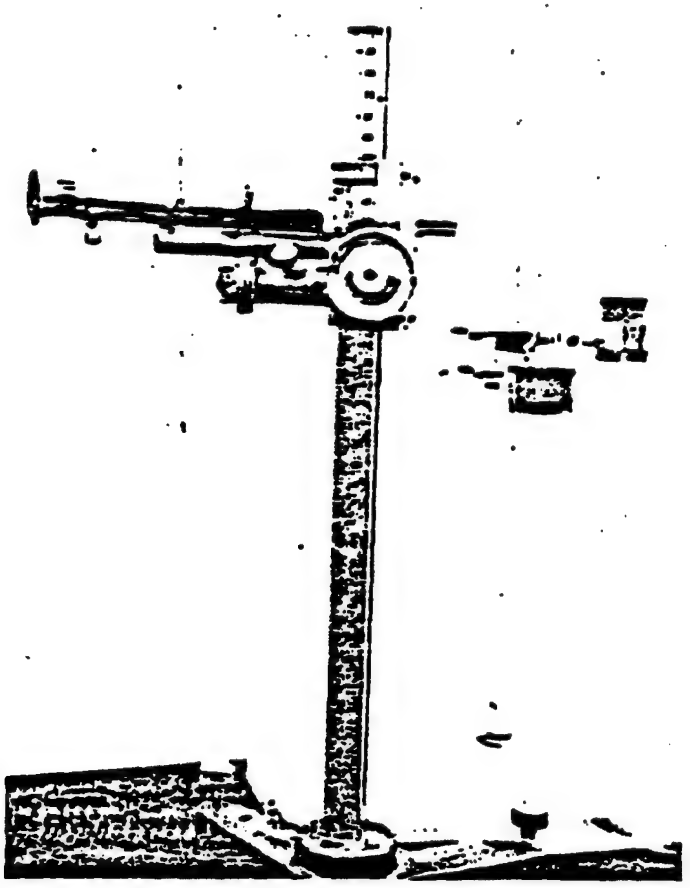


Fig. 8. Calibration of standpipe

short length of flexible transparent plastic tubing, to a pipette or burette having approximately the same inside diameter. The pipette, tubing, and standpipe are filled with water so that the level is at the zero mark on the pipette. The water level in the standpipe is recorded either by using a scale alongside or taking a reading with a cathetometer. The pipette is then raised so that the water level coincides with the bottom mark on the pipette. The distance the water level was raised in the standpipe is then measured. The area of the standpipe is then determined from the equation

$$a = \frac{V}{L}$$

where

a = area of the standpipe, sq cm

V = volume of water measured by the pipette, ml

L = distance the water moved up the standpipe, cm

Since standpipe diameters may not be uniform, the measurements should be made at two or three points along its length and the results averaged.

7. Weight and Force Measurements. Two of the most frequent measurements made in the soils laboratory are weight and force. Weight is the force of gravity acting on a mass and is measured by using balances or scales.

a. Balances and Scales.

(1) Balances and scales measure weight by comparing equal masses: one unknown or to be weighed and the other, known (calibrated weights). It is beyond the scope of this manual to present procedures for calibrating all available types of balances. A few of the types in common use in soils laboratories are two-pan general laboratory, two-pan analytical, Harvard trip, triple beam, torsion (knife edges replaced by steel bands), single-pan optical projection, single-pan "fan" type, and single-pan digital with electronic null indicator. Balances are calibrated using weights of known accuracy with a precision suitable for the balance being calibrated. National Bureau of Standards (NBS) tolerances for weights are, as outlined in Circular 547 (reference 9), as shown in the tabulation on the following page. The NBS should calibrate weights if suitable testing facilities for this purpose are not conveniently available elsewhere. Weights for calibration should be sent to NBS, ATTN: Mass and Volume Section (2.06), Washington, D. C. 20234. Care should be taken that tables and floors on which the balances are placed do not deflect while weighings are being made. This is especially true for

Class		Grams							Milligrams					
		100	50	20	10	5	2	1	500	200	100	50	20	10
S	Individual (mg)	0.25	0.12	0.074	0.074	0.054	0.054	0.054	0.025	0.025	0.025	0.014	0.014	0.014
	Group (mg)	None		0.154		0.105				0.055			0.034	
S-1	Individual (mg)	1.0	0.6	0.35	0.25	0.18	0.13	0.10	0.08	0.060	0.050	0.042	0.035	0.030
	Group	Two-thirds of the weights in a set must be within one-half individual tolerances.												
P	Individual (mg)	2.0	1.2	0.70	0.50	0.36	0.26	0.20	0.16	0.12	0.10	0.085	0.070	0.060
	Group	No group tolerances for this class.												
Q	Individual (mg)	9.0	5.6	3.0	2.0	1.3	0.75	0.50	0.38	0.26	0.20	0.16	0.12	0.10
	Group	No group tolerances for this class.												

single-pan balances, which may have optical projection systems for the smaller weights.

(2) To calibrate two-pan balances (general laboratory, analytical, or single- or double-beam Harvard trip), first level the instrument and then balance the beam; next, check the accuracy of the sliding weight on the beam by placing the appropriate weight in the left pan and moving the sliding weight to the extreme right position (1 g, 10 g, etc.). The balance should remain balanced if the rider or sliding weight is correct. The accuracy of the larger weights made with these balances depends upon the accuracy of the weights used in the right pan. However, it is good practice to test the operation of the balance at half- and full-rated loads. The beam should remain balanced when weights-say 100 or 200 g-are placed in each pan. To calibrate a triple-beam balance (Fig. 9), the procedure is similar to that preceding except there are three riders (sliding weights) to check for accuracy. Some triple-beam balances have auxiliary weights that are hung on the beam to increase the capacity. The accuracy of these should be checked by placing them on the beam and putting the corresponding weight in the pan of the balance. These weights should be used only on the balance they were calibrated with and never exchanged to another balance without recalibration. To calibrate a single-pan balance using optical projection, level the balance and adjust the optical scale to zero. Add a calibrated weight to the pan equal to 1/4, 1/2, 3/4, and total capacity of the optical scale. If the balance reading does not correspond to the calibration weight on the pan, it may be corrected by making adjustments according to the manufacturer's instructions. If no instructions are supplied with the balance, a trained repairman is needed. For all calibrations of balances and scales, heat sources, air currents, and vibrations detrimental to the process must be eliminated.

b. Deadweights. Deadweights are pieces of metal of suitable shape and known weight (Fig. 10). The smaller weights are usually made of brass or aluminum; the larger ones are made of cast iron, steel, or lead. They are used either directly or in conjunction with lever systems

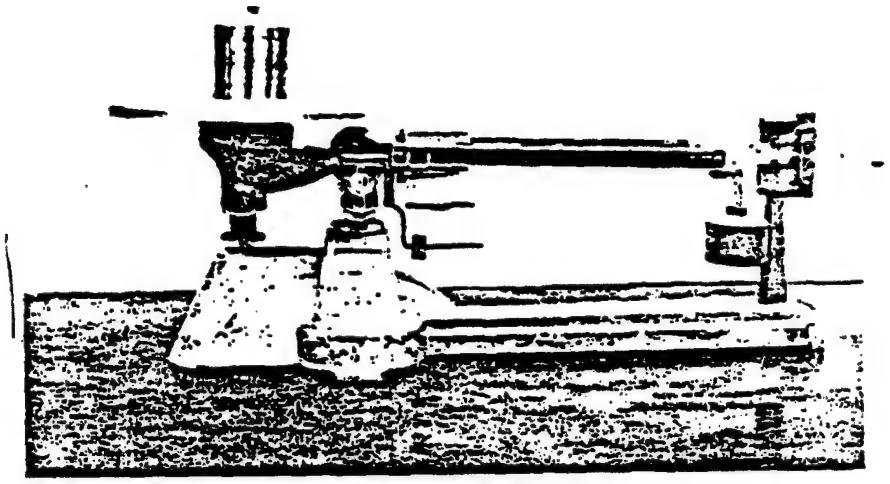


Fig. 9. Calibration of auxiliary weight on triple-beam balance

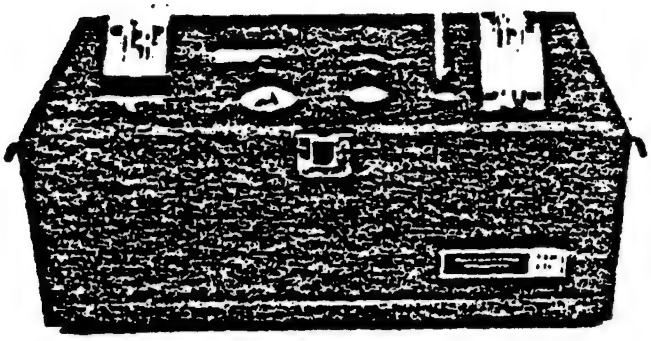


Fig. 10. Deadweights

(consolidation and direct shear tests) or hydraulic systems (dead load testers for pressure gages) to apply forces to test specimens, or as primary standards for the calibration of other force-measuring equipment (proving rings, load cells, etc., Fig. 11). Deadweights can be

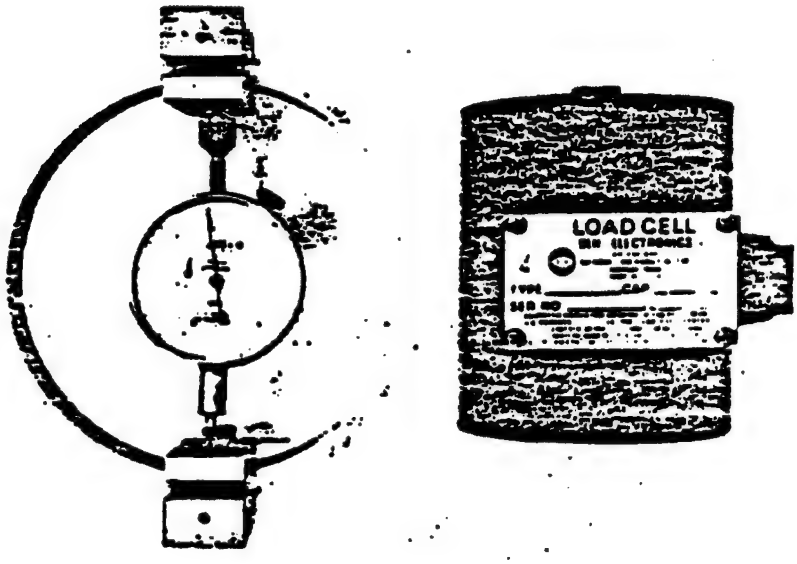


Fig. 11. Load ring and load cell

calibrated to the desired degree of accuracy using scales or load cells having the required accuracy. While the force deadweights apply is due to gravity and is therefore not a constant but varies with elevation, this variation can be neglected for all but the most exacting research.

c. Load Frames and Rings. Load frames and rings are often used for measuring loads or forces in laboratory tests. When measuring loads, care should be taken that the capacity of the frame or ring is not exceeded. In the event overloading occurs during a test, the frame or ring should be recalibrated to determine if there has been a permanent change in the calibration. If rings are subjected to both tension and compression during the conduct of a test, they need to be so calibrated. It is usually sufficiently accurate to use the increasing load table to determine the loads in a test after maximum has been reached and loads are decreasing.

d. Proving Rings. Proving rings used as primary standards for the calibration of rings and frames on equipment should be calibrated either

by the NBS or a facility having calibration capabilities equal to NBS. The calibration of such rings is beyond the scope of this manual. Specifications of the NBS for proving rings for calibration purposes are contained in NBS Circular 454 (reference 15). Quoting from NBS Circular 454, "Proving rings are usually calibrated for 10 approximately equally spaced loads from 10 percent capacity load to capacity load. A preliminary preload to capacity is desirable to stabilize the no-load reading of the ring." While this reference applies to rings to be calibrated for use as primary standards, it is also applicable generally to the calibration of load rings or frames that are installed on equipment. Load rings and frames may be calibrated using the procedure given in paragraph f below.

e. Load Cells. Load cells used in soil testing are normally of the strain-gage type. The strain-gage type is essentially a load ring or frame on which several strain gages are cemented. The load can be accurately determined from the change in electrical resistance it causes in the gages. Strain-gage-type load cells may be used as primary standards for the calibration of any load-measuring device or equipment if their calibration meets previously stated proving ring calibration requirements. Rather complex electronic equipment is required for their operation. The load cells themselves, however, are rugged and hold a constant calibration over long periods of time. Another type of load cell is the hydraulic load cell which is essentially a flexible liquid-filled capsule to which is attached a Bourdon-type pressure gage. This type of load cell is self-contained and requires no external source of power or complex apparatus; however, it usually does not measure with as high a degree of accuracy as the electronic load cell. Also, it is not adaptable to automatic recording as is the electronic load cell. Load cells are calibrated using a procedure similar to that given in the following paragraph.

f. Procedure for Calibration of Load Rings, Frames, and Load Cells. The device should be calibrated at approximately the temperature at which it will be most often used. The following procedure should be used in calibrating a load ring or frame. (A similar procedure is followed in calibrating load cells, except that instead of recording deflection, output voltage is recorded for strain-gage-type load cells, and Bourdon gage readings are made in calibrating hydraulic cells. Initial loading to the rated capacity of the load cell is not required.)

(1) Zero the deflection indicator.

(2) Using a primary standard for load measurement (proving ring, deadweights, or load cell), first load the load ring or frame to its rated capacity. This is done to ensure that the deflection measuring

dial gage is operating properly since such gages often need cleaning and oiling to function smoothly. Loading may be accomplished by any convenient means.

(3) Unload the load ring or frame.

(4) Re-zero the deflection indicator.

(5) Repeat steps (1), (2), (3), and (4) until the zero reading on the deflection indicator becomes constant. (It is often necessary to wait for a minute or two after the release of the load for the deflection indicator to come to rest.)

(6) Place a load of one-tenth capacity of the device, and record the deflection reading.

(7) Continue step (6) until the capacity of the device is reached.

(8) Remove the load and record the no-load reading of the indicator.

(9) Repeat steps (6), (7), and (8) for two additional runs and average the deflection readings for the three runs at each load. Table 2 gives typical load-ring data including computation of calibration factors (rati of load to corresponding deflection).

Table 2. Observed Deflections Under Calibrated Loads

Applied Load[1] lb	Deflection, 0.0001-in. Units				Calibration Factor lb/div
	Run 1 Div	Run 2 Div	Run 3 Div	Avg Defl Div	
0	0	0	0	0	
5	48.8	48.5	49.0	48.77	0.10252
10	97.4	97.9	97.7	97.67	0.10238
15	146.4	147.3	146.4	146.70	0.10224
20	195.4	196.2	196.1	195.90	0.10209
25	245.0	245.5	245.1	245.20	0.10196
30	294.4	295.0	294.7	294.70	0.10180
35	344.0	344.7	344.2	344.30	0.10166
40	394.0	394.0	394.0	394.00	0.10152
45	443.8	444.1	444.0	443.97	0.10136
50	494.0	494.0	494.0	494.0	0.10121
0	0	0	0	0	

(1) If it is desired to determine the hysteresis, applied loads are decreased in decrements similar to the increments used in the loading schedule, and the corresponding deflections are recorded.

The calibration factors are plotted for a 50-lb compression load ring in Fig. 12. The calibration factor for load rings in compression decreases with increasing load, and for a load ring in tension increases with increasing load. In using the ring, the load is computed by multiplying the ring deflection by the calibration factor, which is read from the calibration graph. For frequently used rings, it is preferable to compute a table of ring deflection versus load (Table 3). Such a table is much easier to read, and the possibility of error in reading is much less than when a graph of load versus deflection is used.

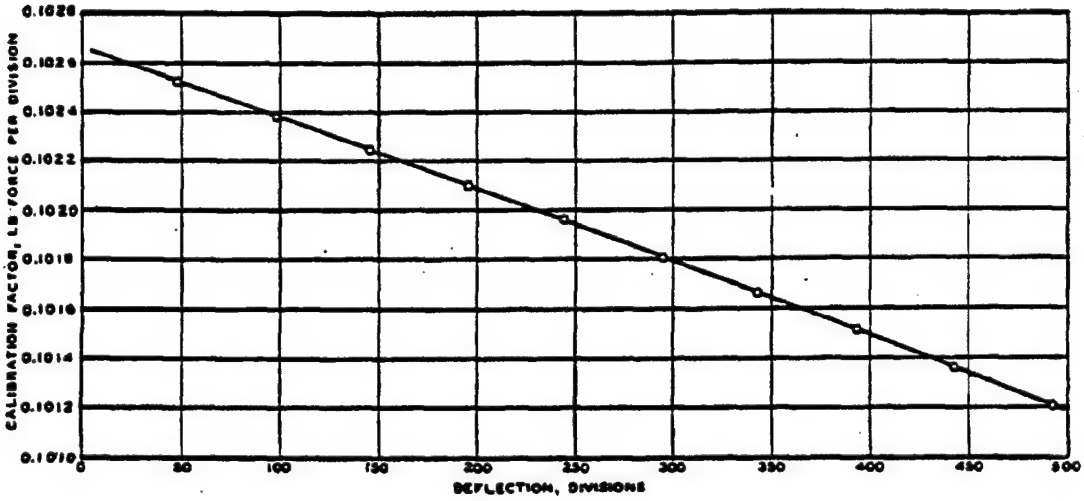


Fig. 12. Calibration factors for a 50-lb compression load ring

g. Inspection of Knife Edges in Lever Systems. The accuracy .of force application by a lever system should be determined for new equipment before being used in testing. The continuance of accuracy of force application by a lever system to a large extent depends upon the condition of the knife edges employed. The design of satisfactory knife edges involves a compromise between capacity and sensitivity. The sensitivity of a knife edge increases as the angle between the two planes forming the edge decreases. The capacity of a knife-edge increases as the angle between the two planes forming the edge increases. To prevent deformation under load, knife edges should be made of hard materials; for large loads, the material must also be of high strength. High-strength alloy steels are often used in knife-edge construction. The hardness may be increased by nitriding or case-hardening, which forms a thin, very hard layer on the surface of the knife edge. The condition of knife edges can be most readily determined by visual

Table 3. Ring Deflection Versus Load for a 50-lb Compression Ring

Deflection Divisions	Computed Load, lb									
	0	1	2	3	4	5	6	7	8	9
0	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
20	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.0
30	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
40	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
50	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0
60	6.1	6.2	6.3	6.4	6.5	6.7	6.8	6.9	7.0	7.1
70	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1
80	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.1
90	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1
100	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	11.2
110	11.2	11.3	11.5	11.6	11.7	11.8	11.9	12.0	12.1	12.2
120	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2
130	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2
140	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2
150	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2
160	16.3	16.4	16.5	16.6	16.8	16.9	17.0	17.1	17.2	17.3
170	17.4	17.5	17.6	17.7	17.8	17.9	18.0	18.1	18.2	18.3
180	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.2	19.3
190	19.4	19.5	19.6	19.7	19.8	19.9	20.0	20.1	20.2	20.3
200	20.4	20.5	20.6	20.7	20.8	20.9	21.0	21.1	21.2	21.3
210	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1	22.2	22.3
220	22.4	22.5	22.6	22.7	22.8	23.0	23.1	23.2	23.3	23.4
230	23.5	23.6	23.7	23.8	23.9	24.0	24.1	24.2	24.3	24.4
240	24.5	24.6	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4
250	25.5	25.6	25.7	25.8	25.9	26.0	26.1	26.2	26.3	26.4
260	26.5	26.6	26.7	26.8	26.9	27.0	27.1	27.2	27.3	27.4
270	27.5	27.6	27.7	27.8	27.9	28.0	28.1	28.2	28.3	28.4
280	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4
290	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4
300	30.5	30.6	30.7	30.8	30.9	31.0	31.1	31.2	31.3	31.4
310	31.5	31.6	31.7	31.8	31.9	32.0	32.1	32.2	32.4	32.5
320	32.5	32.6	32.7	32.9	33.0	33.1	33.2	33.3	33.4	33.5
330	33.6	33.7	33.8	33.9	34.0	34.1	34.2	34.3	34.4	34.5
340	34.6	34.7	34.8	34.9	35.0	35.1	35.2	35.3	35.4	35.5
350	35.6	35.7	35.8	35.9	36.0	36.1	36.2	36.3	36.4	36.5
360	36.6	36.7	36.8	36.9	37.0	37.1	37.2	37.3	37.4	37.5
370	37.6	37.7	37.8	37.9	38.0	38.1	38.2	38.3	38.4	38.5
380	38.6	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5
390	39.6	39.7	39.8	39.9	40.0	40.1	40.2	40.3	40.4	40.5

examination of the edge proper under 7X and 10X magnification to reveal any deformities (chipping or dulling of the edges) that may have occurred. Regrinding or replacement of the knife edge may be necessary to restore a lever system to proper operating condition.

8. Pressure Measurements.

a. Primary Standards for Pressure Measurements. Several types of equipment are available that can be used as primary standards for the calibration of pressure measuring devices. Three types are described in the following paragraphs.

(1) Dead Load Tester. The most frequently used primary standard is the dead-load tester (Fig. 13). This is a hydraulic system in which an accurate pressure is obtained by balancing calibrated weights on a vertical piston of accurately known area. Accuracy is usually 0.1 percent of full range. These instruments are made in a wide span of pressure ranges from low to very high.

(2) Precision Laboratory Test Gages. These are Bourdon-tube-type gages, usually 12 in. or more in diameter, with an accuracy of 0.1. percent or better of full-scale range (Fig. 14). A typical certificate of calibration as supplied by the manufacturer is shown in Fig. 15.

(3) Quartz Tube Pressure Gage. This device, consists of a capsule containing a quartz spiral Bourdon tube that has its free end attached to a pointer or, as in the device pictured in Fig. 16, the free end has a mirror attached. The rotation of the mirror is measured by means of photoelectric cells that convert the rotation into a digital reading. The digital reading is multiplied by a calibration factor to give the pressure in pounds per square inch. Interchangeable capsules are available for any desired pressure range. The calibration certificate for the device in Fig. 16 is shown in Fig. 17. Accuracy for some of these devices is in the order of 0.015 percent full-scale reading.

b. Bourdon Tube Pressure Gages. The most widely used instrument for the measurement of fluid or gas pressures is the Bourdon tube gage. Gages for the measurement of vacuum and low pressure (maximum 15 psi) often use a diaphragm or bellows, as this construction more readily develops the force necessary to actuate the mechanism. Both types of gages require a volume change to indicate pressure; this precludes their use where volume change cannot be tolerated (direct measurement of pore water pressure). Several categories of Bourdon tube gages, listed in order of accuracy, are described in the following subparagraphs.

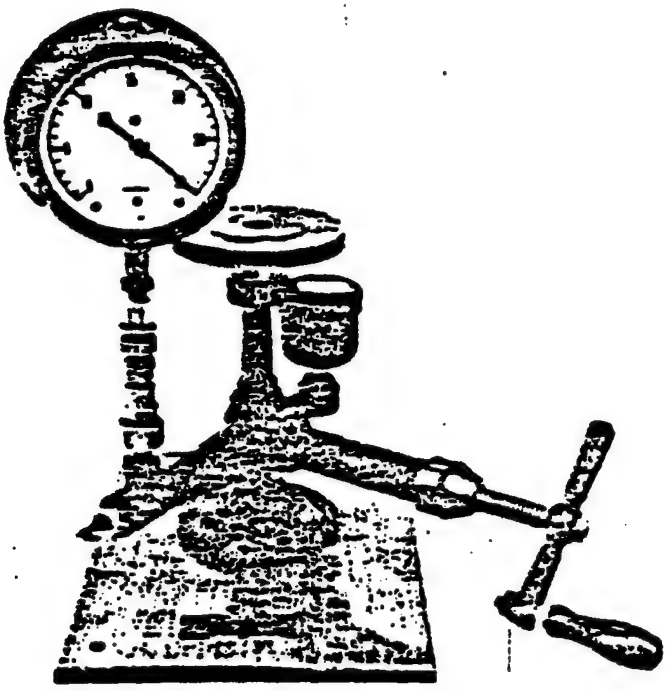


Fig. 13. Dead load gage tester

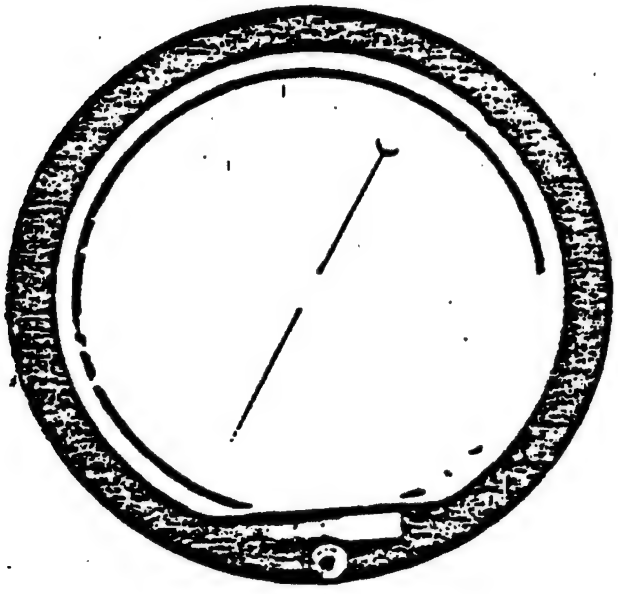


Fig. 14. Precision laboratory test gage

HEISE BOURDON TUBE CO., INC.

Manufacturers of the Heise Gauge NEWTOWN, CONN.

CERTIFICATION REPORT

of

HEISE GAUGE No. 53685

This gauge has been calibrated with a piston gauge which has been compared with master piston gauges whose effective areas were determined with an estimated accuracy of 2 parts in 100,000 by the National Bureau of Standards Reports No. P6744 and No. P6745. The weights for these dead weight piston gauges have also been certified by the Bureau of Standards to have an average accuracy of within one part in 33,000.

READING NUMBER	Calibrated DEAD WEIGHT —psi— —kg—/sq cm GRADUATED	* GAUGE READING (Deviation from Dead Wt. —psi— —kg—/sq cm
1	1 Kg per Sq Cm.	—
2	2	—
3	3	—
4	4	—
5	5	—
6	6	—
7	7	—
8	8	—
9	9	—
10	10	—
11	11	—
12	12	—
13	13	—
14	14	—
15	15	—
16	16	—
17	17	—
18	18	—
19	19	—
20	20 Kg per Sq Cm.	

Room Temperature at Test 70°F

Maximum Hysteresis 0.02 Kg per Sq Cm.

* Remarks: Deviations are indicated when error is 0.02 Kg per Sq Cm. or more

Date Tested 3-19-68

Signed C. K. Arnott

Fig. 15. Certificate of calibration for precision test gage

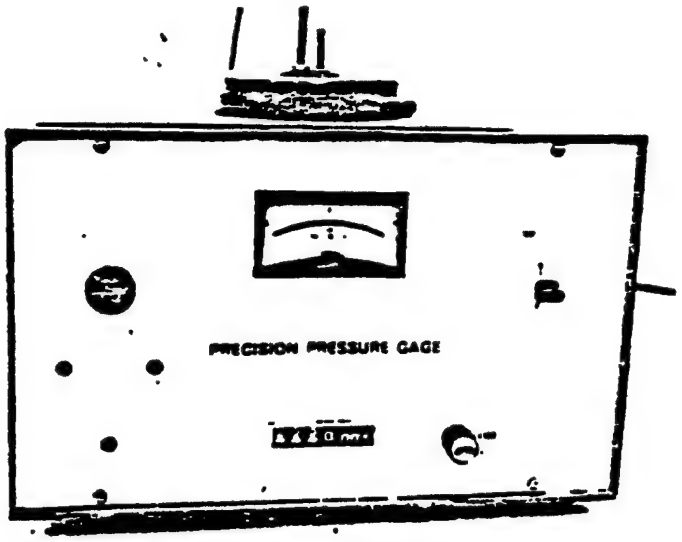


Fig. 16. Quartz tube pressure gage

TEXAS INSTRUMENTS
INCORPORATED

149	1111				5-29-67
1	3	1966		682	
0-100 in Hg		125 in Hg		44.0 Deg C	
0.0000	0.000				
2.4956	5.049	.49928			
4.9972	10.097	.49893			
7.4868	15.139	.49858			
9.9823	20.180	.49866			
12.4778	25.219	.49870			
14.9735	30.253	.49808			
17.4691	35.284	.49510			
19.9647	40.332	.49525			
22.4601	45.377	.49545			
24.9559	50.353	.49560			
27.4514	55.369	.49579			
29.9470	60.381	.49595			
32.4426	65.396	.49609			
34.9382	70.408	.49622			
37.4338	75.416	.49636			
39.9294	80.422	.49650			
42.4245	85.423	.49664			
44.9201	90.425	.49677			
47.4156	95.422	.49690			
49.9112	100.416	.49704			

Fig. 17. Calibration certificate for quartz tube gage

(1) Test Gages. The general purpose test gage has an accuracy of 1/4 of 1 percent full-scale range, a diameter of 4-1/2, 6, or 8-1/2 in., a knife-edge pointer, and a mirrored dial. General purpose test gages are recommended for such applications as measurement of chamber pressure in triaxial testing. Their greater accuracy and superior construction compared to the gages described in subparagraphs (2) and (3) below are well worth the higher initial cost. A means for zero setting of the pointer is provided. Calibration procedure for these gages is given in paragraph d. Three types of test gages are shown in Fig. 18.

(2) High Quality Gages. These gages are manufactured primarily for the process chemical industry. They are sold under a variety of trade names such as Mastergauge, Duragauge, and Supergauge (Fig. 19). Accuracy is 1/2 of 1 percent of full scale; dial size is 4-1/2 in. in diameter or larger. A provision is made for zeroing the gage pointer. Cases for these gages are cast metal or molded one-piece plastic. These gages are considerably less expensive than the general-purpose test gages and can be used in soils laboratory testing. Calibration procedure for these gages is given in paragraph d.

(3) "Industrial" Gages. These gages are similar in case construction to those described above. Dials are 3-1/2 in. in diameter and larger. Accuracy is 1. percent over the middle half of the range, and 1-1/2 percent over the remainder. No means for zero setting of the pointer is provided. Because of their poorer construction and relatively low accuracy, it is not recommended that industrial gages be calibrated. Use of these gages should be limited to those places where accuracy of pressure measurement is not important.

c. Transducers. Several types of transducers are used in the measurement of pressure. The calibration procedures as given by the manufacturers should be followed.. A deadweight gage tester or a precision laboratory test gage should be used as a primary standard. Where the sensing element in the transducer consists of strain gages connected to form a four-arm bridge (Fig. 20), the output is dependent upon the input voltage. In this type of system, it is imperative that high quality power supplies be used to ensure a constant input voltage. Transducers usually have good linearity and low hysteresis. Their very small volume change with pressure makes them particularly suited for the measurement of pore water pressure in soils testing. The procedure for calibration of transducers is given in paragraph d.

d. Procedure for Calibration of Pressure Gages and Transducers (Fig. 13). All pressure gages should be calibrated before being first used. Gages that have been accidentally subjected to excess pressure or have been dropped should be checked before using. The gage to be

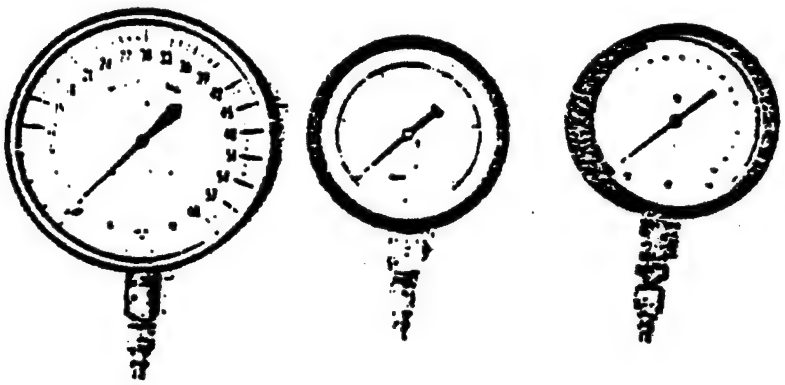


Fig. 18. Typical general purpose Bourdon tube test gages

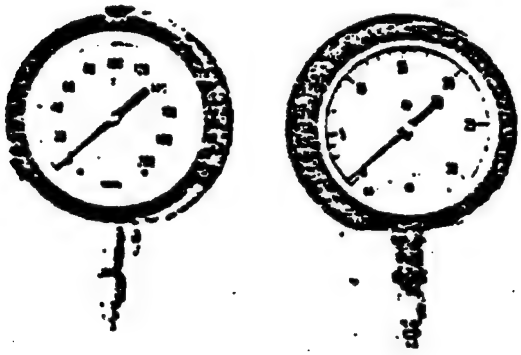


Fig. 19 "High quality" gages

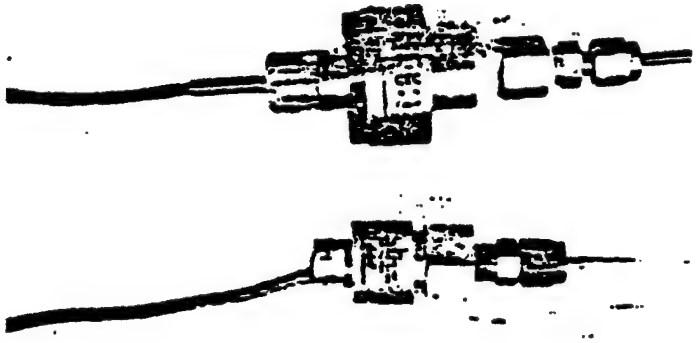


Fig. 20. Typical transducers in housings

calibrated should be connected to a primary standard for the measurement of pressure, examples of which were described in paragraph a (Fig. 13). The gage must be mounted in the position in which it is designed to be used (usually vertical). With no pressure applied, the pointer should be set on zero if necessary.

(1) Slowly increase the pressure on the gage and observe the movement of the pointer to full range of pressure.

(2) Slowly release the pressure and observe the zero position of the pointer; reset if necessary.

(3) Select approximately ten equally spaced intervals of pressure covering the range of the gage. This number may be increased or decreased, depending upon the construction of the gage. Generally, it is more convenient to use the major divisions of a gage as check points in the calibration.

(4) Apply pressure to the gage in the desired increments, reading the primary standard and the corresponding reading of the gage being calibrated.

(5) If the gage reading does not correspond to the primary standard, a table of true pressures versus gage readings should be made and used to obtain the correct test pressures.

e. Manometers. The accuracy of manometers depends upon the accuracy of measurement of the head of liquid and its density. Calibration of manometers would involve a check on the accuracy of the scale used to measure height to the surface of the liquid. A cathetometer is very useful for this if the distance to be measured does not exceed 100 cm. For precise measurement, the temperature of the liquid must be determined and its corresponding density obtained. Manometers are very useful for measuring small pressures accurately.

9. Temperature Measurements.

a. Thermometers. Thermometers may be of the following types: (1) liquid-filled glass, (2) bimetallic strip, (3) resistance, and (4) thermocouple. Discussions of each type and methods of calibration follow.

(1) Liquid-Filled Glass Thermometers. A detailed procedure for testing this type of thermometer is given in ASTM Test Method E 77-66 (reference 1); calibration methods for it are beyond the scope of this manual. Mercury filled thermometers often have a separation of the

liquid column during shipment and should be inspected upon receipt. For thermometers with an expansion chamber, separated columns can be joined by heating the bulb (avoid direct flame) until the mercury column is driven into the chamber. Alternatively, the separated portions can be united by cooling the bulb in dry ice to draw the main column and separated portions together. For either remedial method, the thermometer may be tapped against a pad of paper to assist in rejoining the separated column.

(2) Bimetallic Strip Thermometers. Bimetallic strip thermometers are generally of the dial type, where the actuating element is a bimetallic strip that causes a hand to rotate as the temperature changes. This type of thermometer is generally not used where relatively accurate temperature measurements are required. The procedure for bimetallic strip thermometer calibration is similar to that for the liquid-filled glass thermometer.

(3) Resistance Thermometers. Resistance thermometers depend upon the change in electrical resistance of a wire, which is caused by a change in temperature. Resistance thermometers are available in several ranges of temperature from subzero -75 C to 300 C. The usual range for an indicator is 50 deg minimum span with an accuracy of 1/2 to 1 percent of the range. An indicator may, with appropriate switches, read temperatures from several sensors. Since the output is an electrical signal, resistance thermometers may be used for the automatic recording of temperatures in remote or inaccessible places. The calibration of resistance thermometers is similar to that for the liquid-in-glass type.

(4) Thermocouples. Thermocouples operate on the principle that when the junction of two different metals is heated, an electromotive force is generated that is proportional to the temperature applied. While thermocouples are primarily used for measuring elevated temperatures (furnaces, ovens, etc.), they may be used for room temperatures or below. The output is an electrical signal that makes it suited for the automatic recording of temperatures. To calibrate thermocouples, the fixed points of melting ice and steam are used. The next higher fixed point is the solidification point of pure tin at 231.91 C.

b. Temperature Variation Within Ovens. Ovens occupy an important place in every soils laboratory, primarily for the numerous determinations of water content required. It is therefore necessary that they be reliable in operation. For most soils testing, the temperature control should maintain the temperature at 110 ± 5 C. The mechanical convection or forced-draft ovens are preferred, as they maintain a more uniform temperature, throughout the oven. To determine the

variation of temperature at various locations within an oven (ASTM E 145-68, reference 3), thermocouples or resistance thermometers should be placed at the eight corners, with 2 in. of air space in all directions. An additional device should be placed at approximately the geometric center of the chamber. The temperatures at the various locations should then be determined periodically for a period of 24 hr. The maximum variation for any location should not exceed ±5 C from 110 C. The ambient room temperature should not vary more than 10 C during the test. The line voltage for electrically heated ovens should not vary more than 5 percent during the test.

10. Time Measurements. The necessity for accurate frequency control that resulted from the development of large integrated electric power distribution networks has made the electric clock a time standard for all but the most precise time measurements. Such networks control frequency within ±0.1 of 1 percent; electric clocks connected to such systems would have a corresponding accuracy in time measurement. It is important that electric clocks used for timing soil tests have some means for indicating an interruption of power. It is possible for some electric clocks to slow down with age and still keep running. Older clocks, particularly those that are noisy in operation, should be checked frequently to determine their accuracy. Stopwatches and wristwatches with sweep second hands are satisfactory and convenient for timing many of the testing operations in the soils laboratory.

11. Other Measurements.

a. Levelness. For checking the levelness of testing equipment, levels of various degrees of accuracy are available from the familiar carpenter's level to the precision machinist's level that is accurate to 0.0005 in. per ft. Any desired degree of accuracy may be obtained by selecting the proper level.

* b. Calibration of Mechanical Compaction Rammers. Mechanical compaction rammers used on the compaction tests described in Appendix VI of EM 1110-2-1906 must be calibrated against the results obtained by the appropriate manual rammer. Calibration consists of comparing the results of compaction using the mechanical rammer with results of compaction using the manual rammer. The compactor must be calibrated independently for standard effort and modified effort compaction, and for use with the sector-shaped foot as well as the circular foot.

(1) Calibration Frequency. The mechanical rammer should be calibrated before initial use, near the end of each period during which the mold was filled 500 times, before use after anything including repairs, which may affect test results, whenever test results are questionable,

* and before use after any 6-month period during which the rammer was not calibrated.

(2) Preliminary Checks. Before beginning calibration, check the mechanical compactor for proper operation and allow the rammer to operate for the equivalent of several compaction specimens. The performance of mechanical compactors is subject to change over time due to variations in the amount of friction in the drop weight guiding mechanisms, and these changes can take place within short period and after little use. Smooth nonbinding operation of the drop weight shaft should be checked over the entire range of movement of the rammer. Improper operation of the raising and release mechanisms can also cause serious errors in the operation of these rammers. Set up the compactor for the compaction procedure to be performed. The height of drop must be checked with the rammer at normal operating speed as this value will differ from the height of drop checked in slow or intermittent operation. The height of drop can most easily be checked using a cathetometer to note the level to which a mark on the rammer shaft rises when in operation. The difference between this height and the height of the mark when at rest in the down position is the height of drop. Allow the rammer to fall on a uniform unchanging surface such as several thicknesses of rubber cut from a truck inner tube placed in the compaction mold.

(3) Calibration Procedure. Sufficient clay soil having a plasticity index of at least 20 should be prepared for compaction as described in Appendix VI of EM 1110-2-1906. Soils of lower plasticity should not be used as these soils will not reliably display differences in density due to differences in rammer performance. For the purpose of calibration testing, any material retained on the No. 4 sieve may be discarded during preparation of the material. Enough soil should be prepared at each water content to compact at least two specimens. Mix batch thoroughly prior to removing material for compaction. Compact specimens at each water content using both the mechanical compactor and the manual rammer. It is desirable to compact both specimens at a given water content before moving on to the next water content so as to minimize any differences due to different setting times. Prepare separate compaction curves for soil compacted with each rammer. The maximum dry density of the soil compacted using the mechanical rammer should differ by no more than 1 pcf from the results obtained with the hand rammer.

(4) Adjustment of Mechanical Rammer. If the results produced by the mechanical rammer differ by more than 1 pcf from that produced by the manual rammer, adjust the height of drop of the mechanical rammer or, if this is not possible, adjust the drop weight to make the results produced by the mechanical rammer match those of the manual rammer. If, after adjustment, the height of drop (in operation) or the drop weight *

* of the mechanical rammer, or the product of the height of drop and the drop weight deviates more than 10 percent from manual rammer specifications, the mechanical rammer should be considered in need of repair or adjustment and removed from service. If, after calibration, the product of the drop height and the drop weight is less than specified for the comparable manual rammer (5.5 lb-ft for standard compaction and 15 lb-ft for modified compaction), the manual rammer should be rechecked for compliance with specifications, and the operator's technique should be observed to verify that compaction blows are being applied properly before proceeding. Verify the adequacy of any changes made in the mechanical rammer by compacting three additional pairs of specimens of clay soil at optimum water content or no more than two percentage points dry of optimum. One specimen of each pair shall be compacted with the mechanical compactor and the other specimen with the manual rammer. Normally, if the soil is mixed thoroughly and care is taken to prevent moisture loss during testing, the water contents of the compacted specimens will remain quite close and the densities of the compacted specimens can be compared on the basis of an anticipated water content common to all the specimens. However, all specimens should be oven-dried and the actual water contents determined to verify assumptions. When preparing soil for these tests, preparation of somewhat more soil than will actually be needed tends to reduce the effect of moisture loss in the unused soil. However, if the water contents of the compacted specimens are found to vary from specimen to specimen on oven-drying, the dry densities of the specimens may be adjusted by shifting the water content dry density plot parallel with the previously obtained compaction curve to an average water content value for the group of compacted specimens. The average dry density of the three specimens compacted with the mechanical rammer should not deviate from the average of the specimens compacted with the manual rammer by more than 1 pcf.

c. Calibration of Hydrometers. The procedures for calibrating hydrometers for particle size determinations as contained in *

EM 1110-2-1906, Appendix V, are repeated here for ready reference. The hydrometer shall be calibrated[1] to determine its true depth in terms of the hydrometer reading (Fig. 21) in the following steps:

(1) Determine the volume of the hydrometer bulb, V_R. This may be determined in either of two ways:

(a) By measuring the volume of water displaced. Fill a 1000-cc graduate with water to approximately 700 cc. The water temperature should be about 20 C. Observe and record the reading of the water level. Insert the hydrometer and again observe and record the reading. The difference in these two readings equals the volume of the bulb plus the part of the stem that is submerged. The error due to inclusion of this latter quantity is so small that it may be neglected for practical purposes.

(b) By determining the volume from the weight of the hydrometer. Weigh the hydrometer to 0.01 g on the laboratory balance. Since the specific gravity of a hydrometer is about unity, the weight in grams may be recorded as the volume in cubic centimeters. This volume includes the volume of the bulb plus the volume of the stem. The error due to inclusion of the stem volume is negligible.

(2) Determine the area A of the graduate in which the hydrometer is to be used by measuring the distance between two graduations. The area A is equal to the volume included between the graduations divided by the measured distance.

(3) Measure and record the distances from the lowest calibration mark on the stem of the hydrometer to each of the other major calibration marks, R.

(4) Measure and record the distance from the neck of the bulb to the lowest calibration mark. The distance H_1 , corresponding to a reading R, equals the sum of the two distances measured in steps (3) and (4).

(5) Measure the distance from the neck to the tip of the bulb. Record this as h, the height of the bulb. The distance, h/2, locates the center of volume of a symmetrical bulb. If a nonsymmetrical bulb is used, the center of volume can be determined with sufficient accuracy

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[1] ASTM hydrometers 151H or 152H (ASTM Designation: E 100-66, reference 2) have a uniform size; therefore, only a single calibration is required, which can be applied to all ASTM hydrometers of this type.

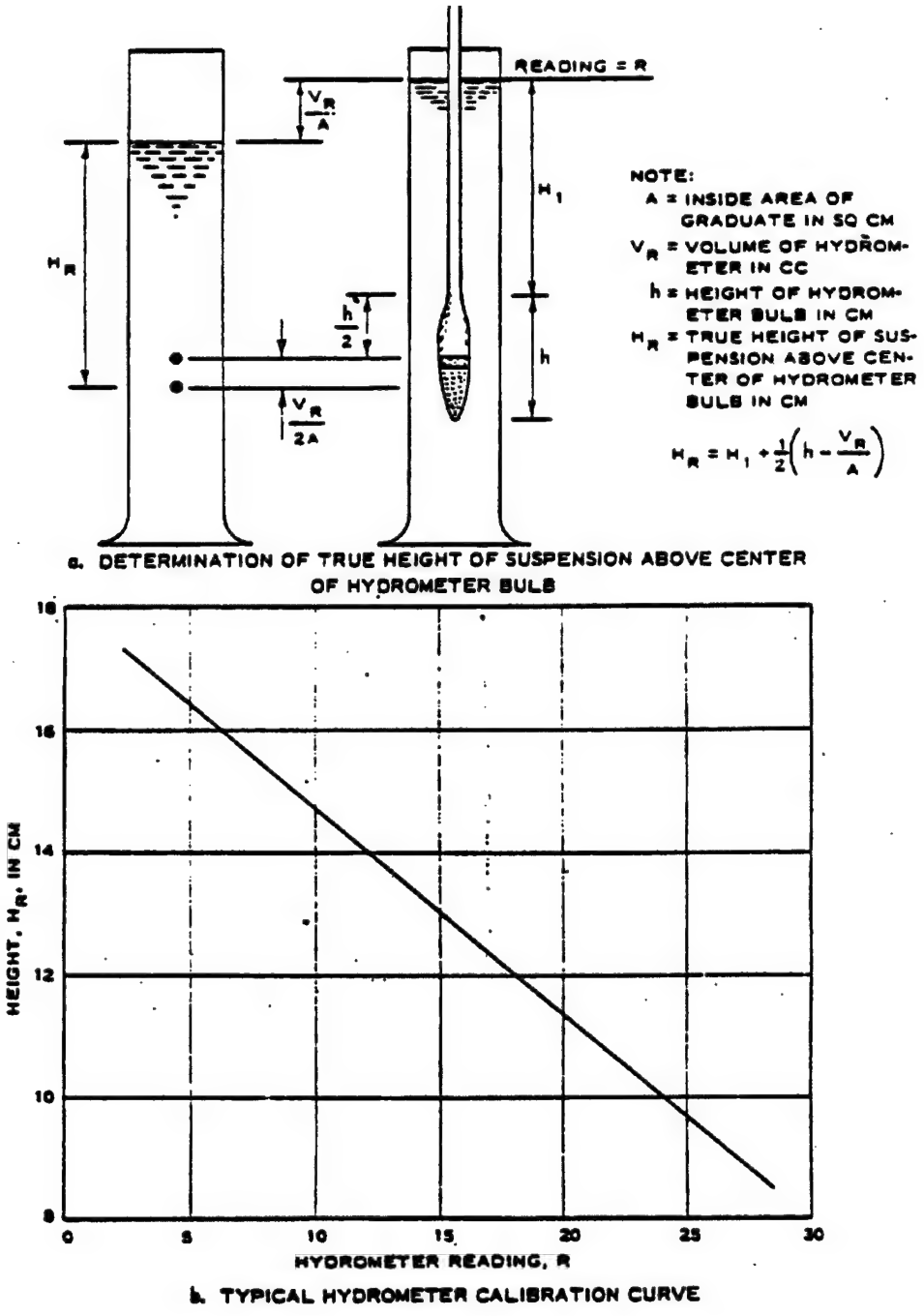


Fig. 21. Hydrometer calibration

by projecting the shape of the bulb on a sheet of paper and locating the center of gravity of this projected area. In this latter case the distance from the top of the bulb to the center of gravity is used in (6) below and in Fig. 21 in place of h/2.

(6) Compute the true distances H_R corresponding to each of the major calibration marks, R, from the equation:

$$H_R = H_1 + \frac{1}{2}\left(h - \frac{V_R}{A}\right)$$

(7) Plot the curve expressing the relation between H_R and R as shown in Fig. 21. The relation is essentially a straight line for hydrometers having a streamlined shape.

d. Compression of Consolidation Equipment. In the consolidation test, it is desired to measure only the change in height of the specimen; therefore, corrections must be applied for any significant deformation in the apparatus itself. For tests using comparatively incompressible soils, such as highly preconsolidated clays or dense sands, an appreciable amount of the total measured deformation may be in the apparatus and porous disks. Therefore, a calibration curve should be prepared for each consolidometer when testing such soils. This is done by placing the consolidometer with submerged porous stones separated by two filter papers in the loading device, applying the load in increments as in the test, and reading the dial indicator for each load. The loads are then decreased as in the rebound portion of the testing, and dial indicator readings are again recorded (Table 4). This procedure is repeated until the deformation becomes essentially constant (about 0.0005 in change between cycles). The total change in dial reading for each load is the correction to be applied to the dial reading during the consolidation test under that same load. Usually, about three cycles are sufficient for the calibration. This procedure should be accomplished before each test where equipment deformation would be detrimental to the test results. However, if it is established that the calibration is the same for an apparatus time after time, the frequency of calibration may be reduced to a semiannual or annual basis. During the calibration for deformation of consolidation equipment, a dummy specimen such as a metal disk of known compressibility is sometimes used to eliminate the need for adjustments to the lever arm system. Note that these determinations of equipment deformation do not take into account deformations resulting from the seating of a soil specimen agaist the top and bottom porous stones, which in some cases may be significant.

Table 4. Deformation of Consolidation Equipment

Load tons/sq ft	Deformation of Apparatus, in. First Cycle	Second Cycle	Third Cycle
0.015	0.000	0.000	0.000
0.25	0.0025	0.0020	0.0019
0.50	0.0041	0.0033	0.0031
1.0	0.0060	0.0049	0.0048
2.0	0.0079	0.0065	0.0062
4.0	0.0095	0.0079	0.0075
8.0	0.0116	0.0095	0.0090
16.0	0.0148	0.0119	0.0112
Rebound			
4.0	0.0118	0.0088	0.0082
1.0	0.0091	0.0064	0.0057
0.015	0.0032	0.0009	0.0001

e. Piston Friction in Triaxial Equipment. In most triaxial equipment in use today, the axial load is applied to the soil specimen by means of a piston passing through the top of the chamber with the applied load being measured outside the chamber. Thus any friction between the piston and the bushing in the chamber will increase the apparent load on the soil specimen. Proper design and construction of the equipment will eliminate friction to a large extent, but where lateral forces on the piston are created by nonuniform deformation of the soil specimen, the piston friction from this cause cannot be avoided. The friction due to lateral forces on the piston may be reduced greatly by proper lubrication and rotation of the piston or bushing or the use of linear ball bushings. Tests by Haussler and also by Warlam (reference 11) indicate that in a well-designed chamber, the friction should not exceed about 1. to 3 percent of the axial load. Quoting from Bishop and Henkel (reference 4, page 175): "For most commercial testing and also for a good deal of research work, the simplicity of the apparatus is more important than the elimination of errors of the magnitudes mentioned above." To determine the effect of lateral force on piston friction, the triaxial piston and bushing are assembled and held fixed with the piston vertical as it would be during a test. A lateral force is then applied to the piston by means of a cord looped over the bottom end of the piston. The distance of the cord below the bushing should be approximately the length of piston below the bushing when the chamber is assembled for testing. The cord is run over a ball-bearing V-pulley and down to a hanger with deadweights used to apply

the load. The force required to move the piston is measured for each of several lateral forces. Since in any triaxial test the magnitude of any lateral force developing against the piston is an unknown quantity, no correction can be made for this effect. However, the results of the above-described procedure should indicate only a small change in piston load with a lateral force applied against the piston. The piston friction introduced by the use of an O-ring seal is usually a constant value and may be subtracted from the measured axial load. Excellent discussions of piston friction are given in reference 14 (page 865) and reference 10 (page 961).

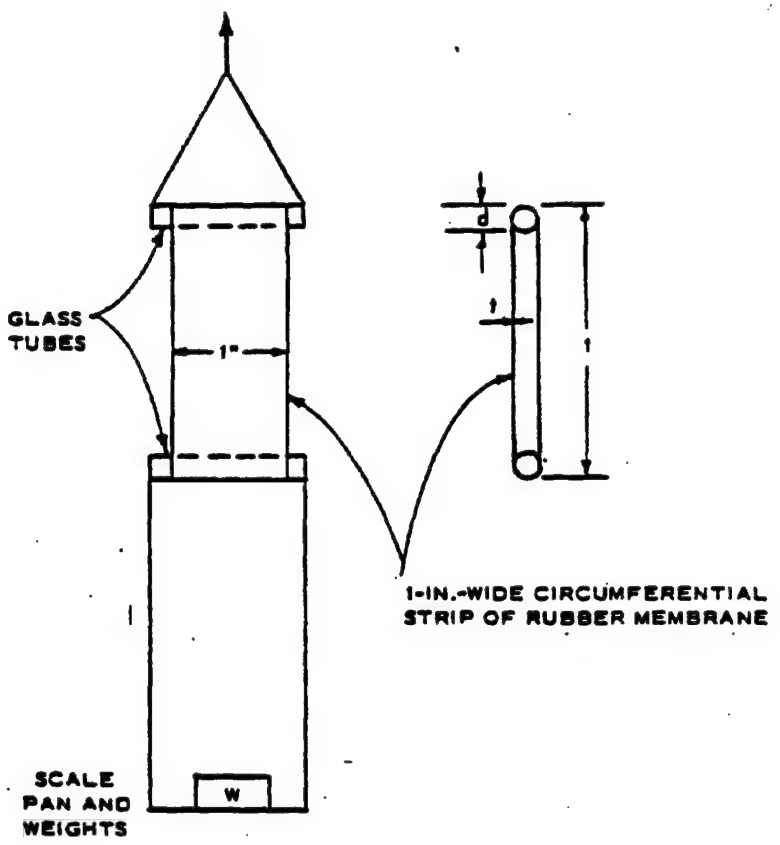
f. Determination of Extension Modulus of Rubber Membrane.

(1) In the triaxial compression test, the soil specimen is inclosed in a rubber membrane. As the sample is deformed either by bulging or shearing, the membrane tends to restrain this deformation, thus increasing the axial load. For most soils tested using membranes of standard thickness, the correction is insignificant and can be ignored. In special testing programs, it may be desirable to apply a correction for membrane restraint.

(2) There have been several investigations of this problem. The earlier works by Henkel and Gilbert (reference 6), and Bishop and Henkel (reference 4, page 56), provided a correction only for the Q triaxial test. A more recent report by Duncan and Seed (reference 5), provides for membrane corrections for Q, R, and S triaxial tests. Membrane, drain, and area corrections are reported by LaRochelle in reference 8.

(3) To compute the correction for membrane restraint, the compression modulus of the rubber membrane must be known. Since this would be difficult to measure on thin membranes, it is assumed that the extension modulus is equal to the compression modulus. The extension modulus is determined by measuring the strain caused by a corresponding weight as shown in Fig. 22. Talcum powder may be used on the glass tubes to decrease the friction of the rubber. The change in length of the rubber membrane due to the weight w is most conveniently measured using a cathetometer.

g. Calibration of Liquid Limit Device. Details of the liquid limit device, with dimensions, etc., are presented in EM 1110-2-1906, Appendix III. Each liquid limit device and grooving tool should be checked upon arrival in the laboratory for compliance with specifications since many do not comply. Thereafter, periodic checks should be made of those adjustments and dimensions that are changed through wear. The frequency of checking depends upon the use.



$$\text{MEAN LENGTH OF MEMBRANE} = 2(l - d - 2t) + \pi(d + t)$$

$$\text{LOAD PER INCH} = \frac{W}{2}$$

$$\text{EXTENSION MODULUS} \quad M = \frac{\text{LOAD PER INCH}}{\text{STRAIN}}$$

Fig. 22. Determination of extension modulus of rubber membrane

(1) Initial Checks.

(a) The hardness of the base of the liquid limit device has been found to have an effect on the results obtained. It is therefore necessary to check the hardness of new devices and recheck old devices that have been in service one year. To test the hardness, measure the height of rebound of a steel ball bearing, 5/16 in. in diameter, when dropped

from a height of 10 in. To have an acceptable hardness, the rebound should be not less than 7.3 in. or more than 9.0 in. Use a plastic or glass tube 10 in. long with marks at the 7.3- and 9.0-in. heights. These marks are easily applied to the tube by using a piece of pres sure-sensitive plastic mending tape on which a line has been drawn. The tube should be of sufficient diameter so that the steel ball falls freely; an inside diameter of approximately 0.5 in. is satisfactory. Several trials should be made near but not exactly on the spot of contact of the cup.

(b) A motor-driven device should be checked for excessive vibration by placing a 250-ml beaker half full of water on the base. No more than a barely perceptible ripple should be observed. The cup and cam follower assembly should weigh 175 ± 15 g. There are several methods for measuring the grooving tool. The optical reticle used with a pocket magnifier, as described in paragraph 5c, is probably the least expensive. The Kansas City District describes a method used in their laboratory as follows: "The grooving tool is inserted, sharp edge up, in a Remington Rand Model G, Catalog No. F72 Film-a-Record Reader, in the place where the film would normally be. The image is magnified approximately 43 times and projected as a silhouette on the ground glass screen from which the exact size and shape are easily obtained. True magnification must be determined before blown-up measurements can be used. True magnification can be determined by inserting a millimeter scale in place of the film and checking the magnified image on the screen. With this blown-up image, any imperfections are readily observed." An overhead transparency projector may be similarly used, but has the disadvantage of requiring a darkened room and a projection screen.

(2) In-Use Checks.

(a) Once a device has been placed in use, the height of fall of the cup should be checked frequently. By means of the height gage, the height of fall must be adjusted so that the shiny contact spot (not the lowest point of the cup) is 10.0 mm above the base. After the adjusting screws are tightened, the height should be rechecked. A flashlight is helpful in making this adjustment.

(b) An alternative method is to attach 1-in. length of black plastic electrician's tape to the bottom of the limit cup such that the near edge of the tape bisects the area of contact and is parallel to the center line of the pin in the cam follower. The cup is placed in the device, and the height gage is moved back under the cup until it just touches the edge of the electrician's tape. The crank is then turned at the specified speed; only a faint click should be produced if the height adjustment is correct.

After the correct drop is secured, the adjusting screws are tightened, a final check on drop made, and the tape is then removed.

(c) When the cup and base become so worn that the flat point of contact exceeds 3/8 in. in diameter, or when a groove that is worn inside the cup can be felt distinctly by hand, the worn item should be replaced or repaired. A worn cup can be remedied by moving the cam follower 90 deg to obtain a new point of impact. The pin on which the cam follower pivots should not be worn sufficiently to permit 1/8 in. side play of the cup.

h. Amplitude of Vibration of Vibratory Table.

(1) The amplitude of vibration has been found to have a significant effect on the maximum density obtained as a part of the relative density test. For this reason, it is desirable to measure the amplitude of each new piece of equipment or of equipment that has had the adjustments on the vibrator changed. Satisfactory measuring devices having the required speed of response are electronic, such as oscillographs or oscilloscopes, together with a suitable sensing device. The accelerometer-type devices are not satisfactory for use as a sensing element because the displacement-time curve is not sinusoidal, and also there are several harmonic frequencies present in the vibration that make the computation of displacement from the acceleration very difficult. The most satisfactory apparatus is an oscillograph, with a differential transformer as the sensing unit, with a suitable power supply. Components that have been found to be suitable are a CEC 124 oscillograph as the recorder with a Collins differential transformer of 0.050-in. capacity and a CEC Model 3140 power supply.

(2) To calibrate the system, the deflection of the trace on the oscillograph is adjusted so that the desired deflection is secured with a measured movement of the core of the Collins gage. For initial calibration, the movement of the core is measured either with gage blocks or a vernier caliper. A mold is filled with soil and assembled with the surcharge and attached to the table. The Collins gage is mounted as close to the mold as possible, with the core attached firmly to the table. The mount for the gage body should be constructed so that no vibration from the table reaches the gage. The vibrator is then operated for two or three minutes, and a record is taken. The amplitude of vibration is then determined from the trace on the oscillograph record.

12. Recommended Calibration Schedule. Table 5 gives general guidance on the frequency of calibration of the more common items of laboratory equipment. Items that are used only infrequently do not need checking as often as the schedule presented in Table 5 indicates,

Table 5. Calibration and Examination

Item	Feature	Frequency
Consolidation rings	Weight and volume	Semiannually
Direct shear specimen cutters	Weight and volume	Semiannually
Compaction molds	Volume	Annually
Load rings, load frames	Load-deflection	Annually
Bourdon gages	Pressure	Annually
Specific gravity flasks	Weight	Once
Balances	--	Annually
Hydrometers	--	Once
Balance weights	--	Annually
Sample containers for water content	Weight	Annually
Oven	Uniformity of temperature	Annually
Compaction rammers:		
Hand	Weight, fall, foot diameter	Annually
Automatic	Comparison with hand rammer	Annually
Liquid limit device:		
Base	Hardness	Annually
Base	Wear	Monthly
Cup	Wear	Monthly
Cup	Height of fall	Daily
Liquid limit device grooving tool	Wear	Weekly
Electric clocks	Wear	Every two years
Stopwatches	Wear	Annually
Lever system knife edges	Wear	Annually

while items in constant use, especially those subject to wear, may need to be checked more frequently than indicated. Also, if any item has been subjected to unusual treatment, it should be recalibrated; for example, a load ring that has been overloaded, dropped, or disassembled should be recalibrated.

13. Permissible Tolerances. To establish the permissible tolerance in a measurement of testing equipment, the required accuracy of test results should be established. For example, the volume of a consolidometer ring must be determined with greater accuracy than the volume of a compaction mold. Table 6 is a guide to be used for items for which

permissible tolerances are not outlined in EM 1110-2-1906. Precise weighing and measuring devices should be used to determine that the tolerances in Table 6 are met.

Table 6. Permissible Tolerances

Item	Maximum Allowable Tolerance
Consolidation ring (4 to 4.5 in. in diameter):	
Weight	0.1 g
Diameter or height[1]	0.025 mm
Direct shear trimming ring:	
Weight	0.01 g
Height	0.025 mm
Length or width	0.025 mm
Volume of compaction molds	0.5%
Load rings and frames	1% of applied load
Bourdon gages	0.5% of full scale or range
Containers for water content test:	
For specimens weighing 1 to 50 g	0.01 g
For specimens weighing 51 to 500 g	0.1 g
For specimens weighing over 500 g	1.0 g

[1] Note that volumetric error $\frac{dV}{V} = 200\frac{dD}{D} + 100\frac{dH}{H}$ and should be <1%.

FOR THE CHIEF OF ENGINEERS:

1 Appendix
APP A - References

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